High Energy Muon Collider and Neutrino Factory:

A Staged Pathway to Discovery

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with input from:

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Big Picture Since ICFA-2005

- LHC is built and will run in 2009:
  - confidence in getting new physics insight ~2012-13
- Growing consensus on the next machine (P5)
  - shiuld be lepton-lepton collider
  - ILC energy reach may not be enough → multi-TeV
  - very serious attention to alternatives (P5 report)
- Alternative schemes:
  - CLIC e+e- linear collider (CDR by ~2010)
  - plasma-wake e+e- linear colliders (emerging)
  - muon collider (aims for DFSR by 2013) - advantages

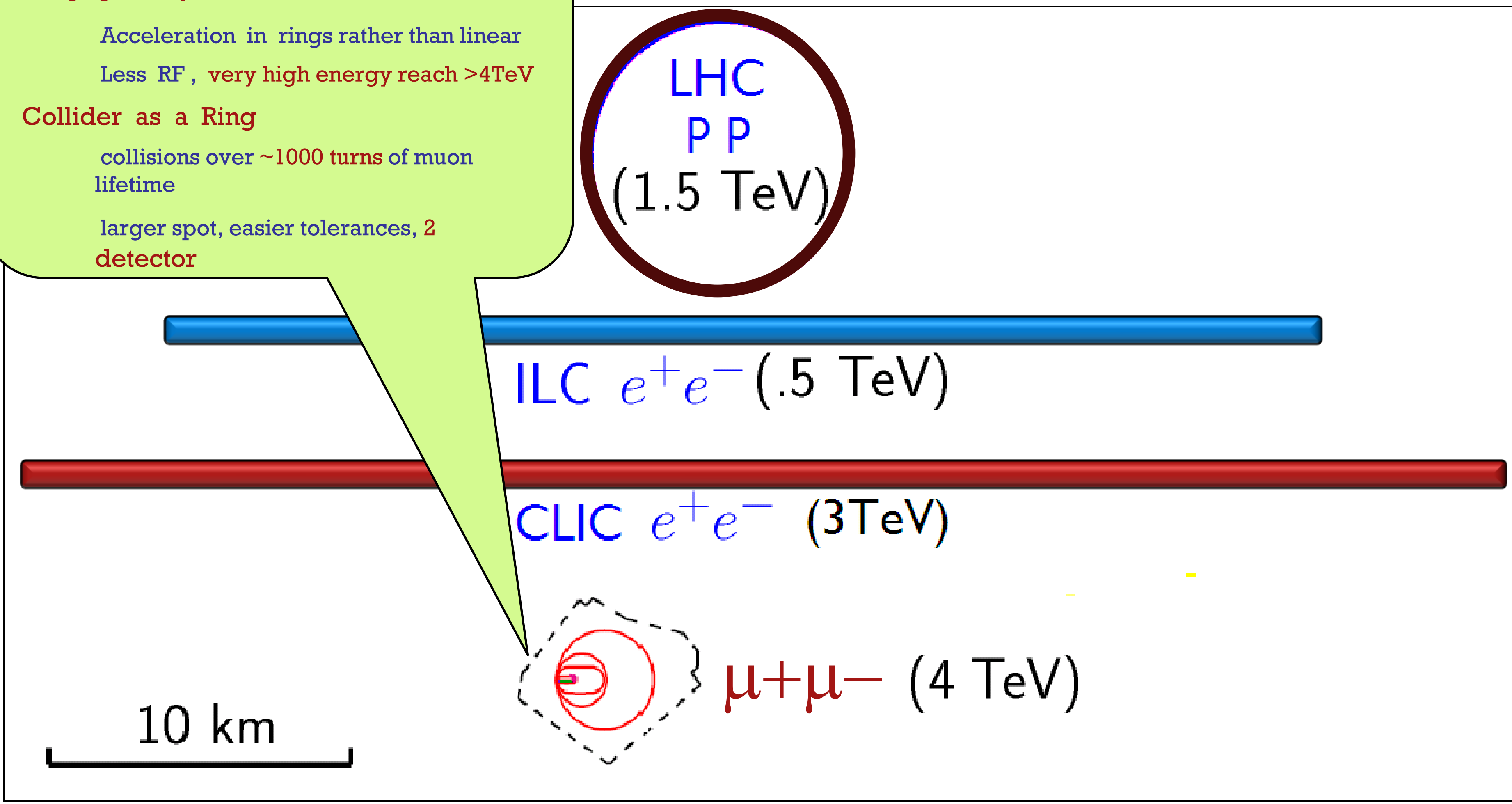
Small Footprint

Negligible synchrotron radiation

- Acceleration in rings rather than linear
- Less RF , very high energy reach >4TeV

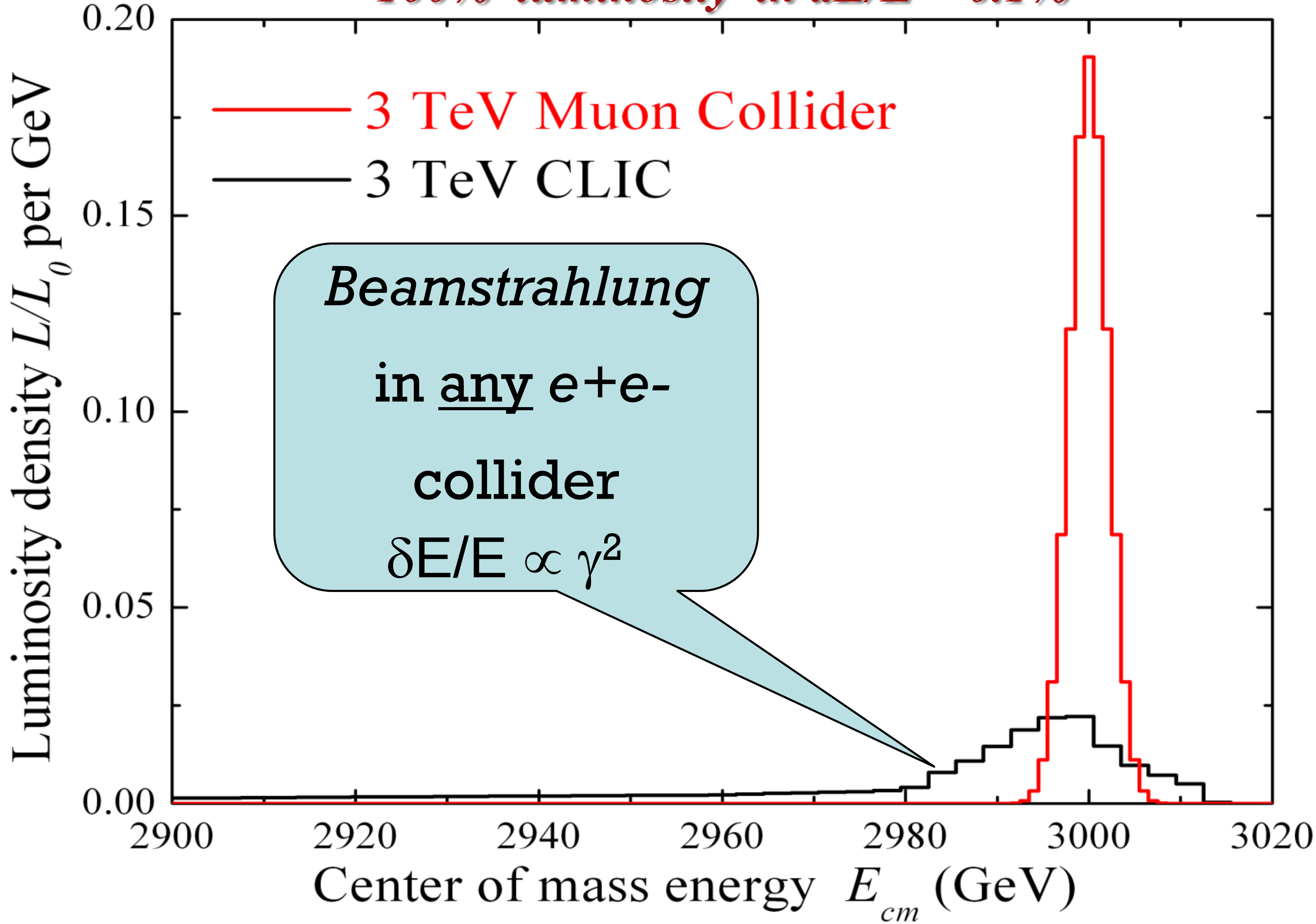
Collider as a Ring

- collisions over ~1000 turns of muon lifetime
- larger spot, easier tolerances, 2 detector



Superb Energy Resolution

100% luminosity in dE/E ~ 0.1%



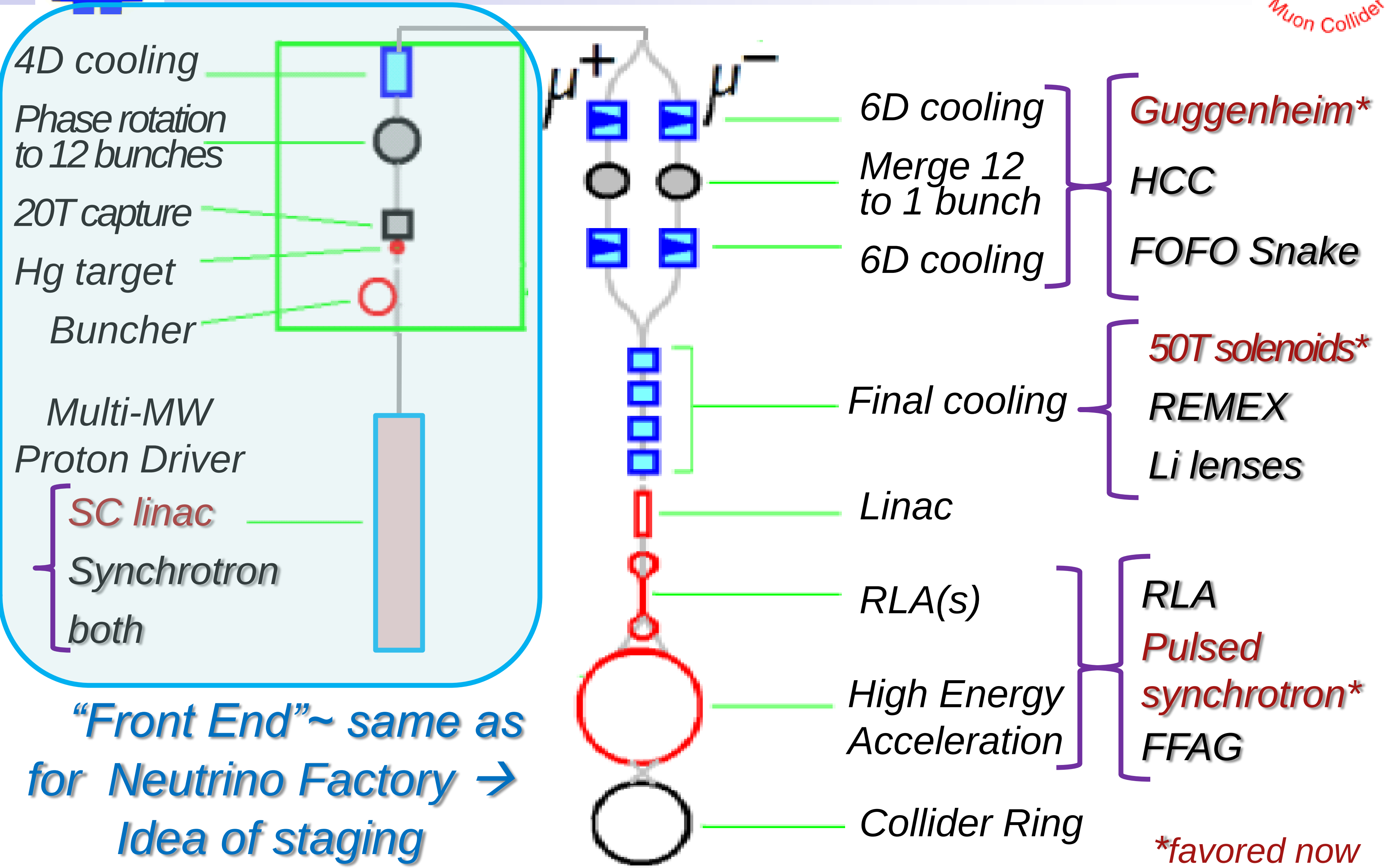
Other Changes Since 2005

- Rapid development of plans for multi-MW proton facilities:
  - FNAL: Project-X
  - CERN: Linac 4, PS Upgrade, SPL
  - RAL: ISIS upgrade to 3-5 MW
  - Europe: ESS
- This is exactly what's needed for a Neutrino Factory or a Muon Collider:
  - thus, Muon Collider/Neutrino Factory offer a natural continuation of the near-future programs

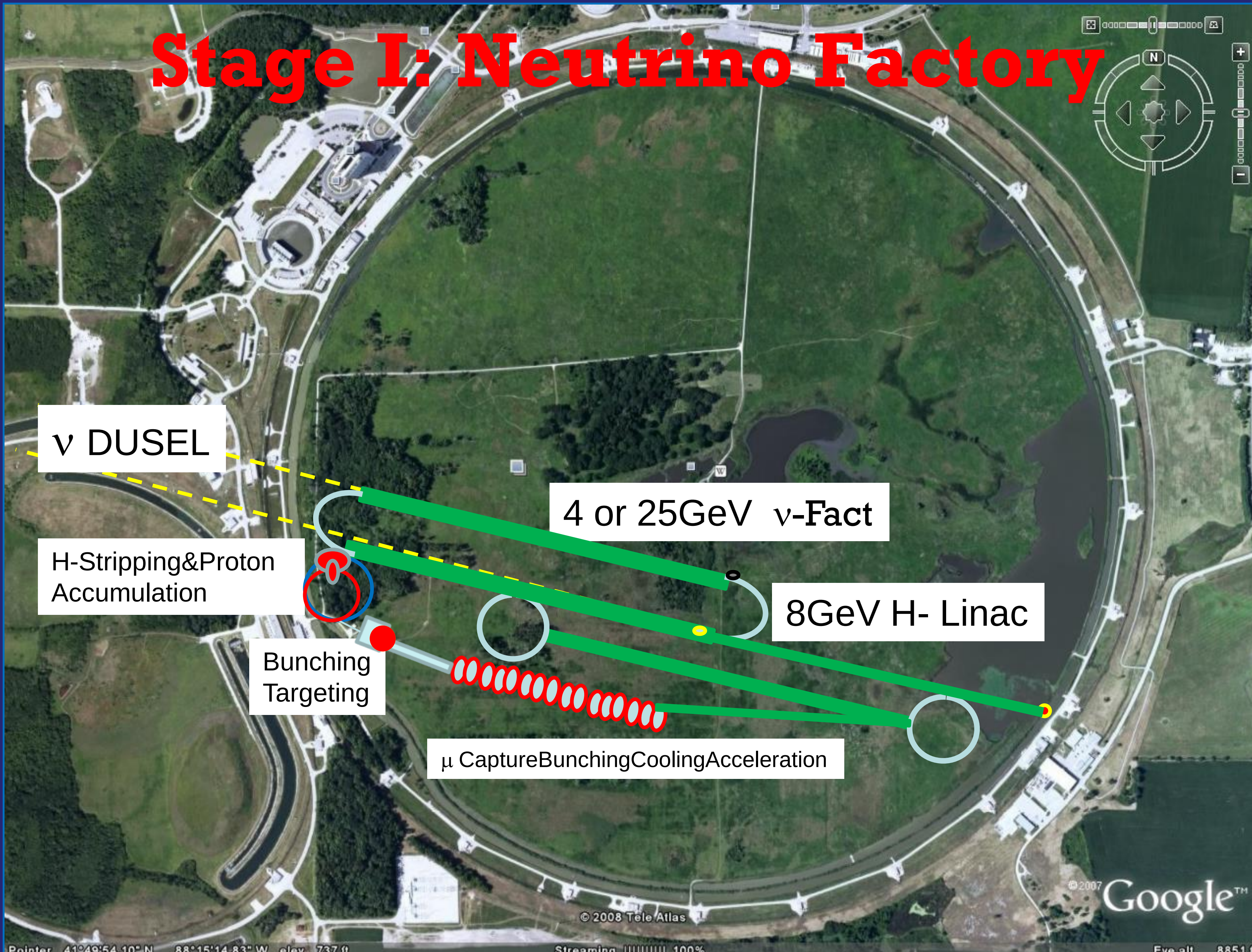
Technical Progress Since 2005

- Successful completion of multi-MW liquid Hg-target experiment MERIT
- Start-up of ionization cooling experiment MICE (1st beam)
- Development of Muon Cooling components (absorbers, coils, RF cavities)
- Revealing results of RF studies (~20MV/m in 201MHz cavity, ~35MV/m in 805MHz, 60MV/m HP RF, in B-field, ionizing beam studies coming)
- SC coils for helical cooling designed and built
- NF Int'l Scoping Study report delivered
- Progress in MC design (ring lattice, RLA, cool)

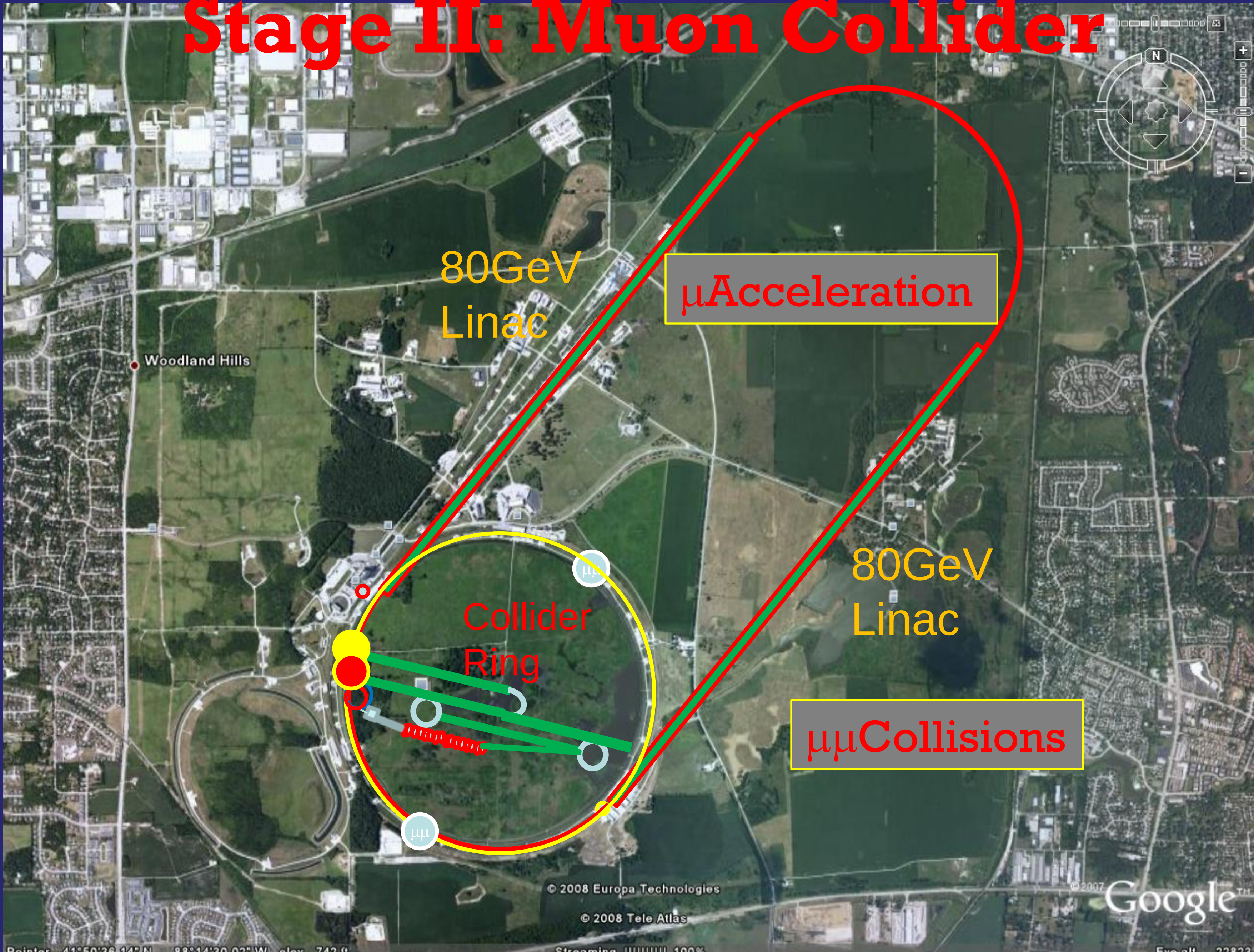
Muon Collider Scheme



Stage I: Neutrino Factory



Stage II: Muon Collider



Muon Collider Parameters

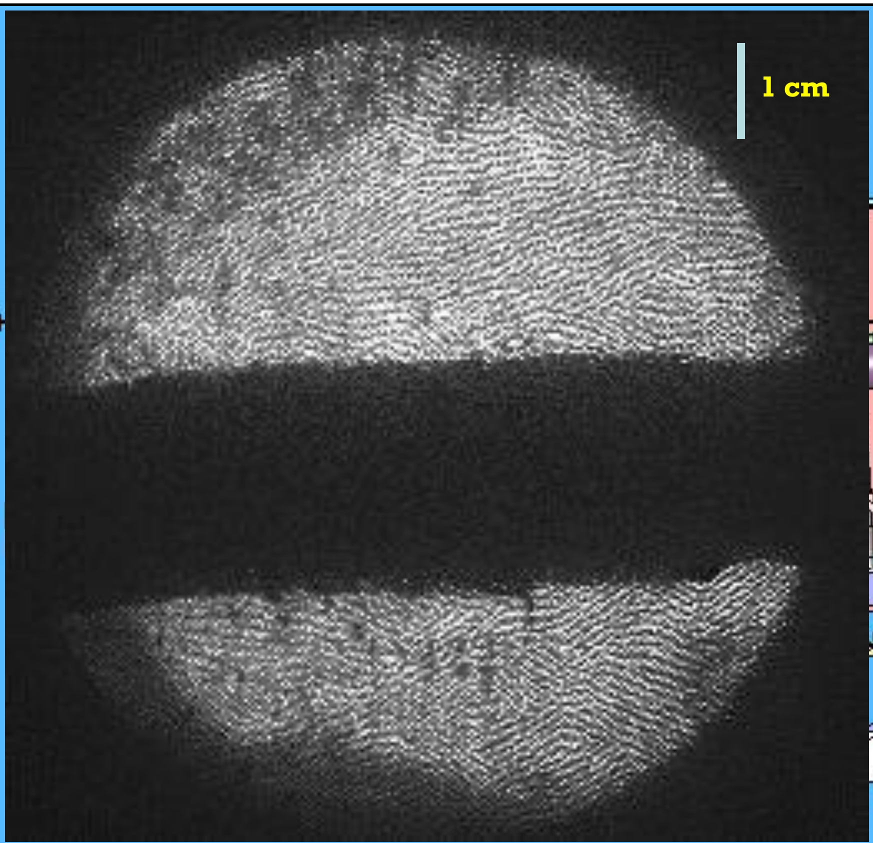
CM Energy	1.5	4	TeV
Luminosity	1	4	10^{34} $cm^{-2}s^{-1}$
Muons/bunch	2	2	10^{12}
Ring circumf.	3	8.1	km
Beta at IP $\beta^* = \sigma_z$	10	3	mm
dp/p (rms)	0.1	0.12	%
Ring depth*	13	135	m
PD Rep rate	12	6	Hz
PD Power	**≈4**	**≈2**	**MW**
Transv.emm. ε_T **	25	25	π mm mrad
Long. emm. ε_L	72,000	72,000	π mm mrad

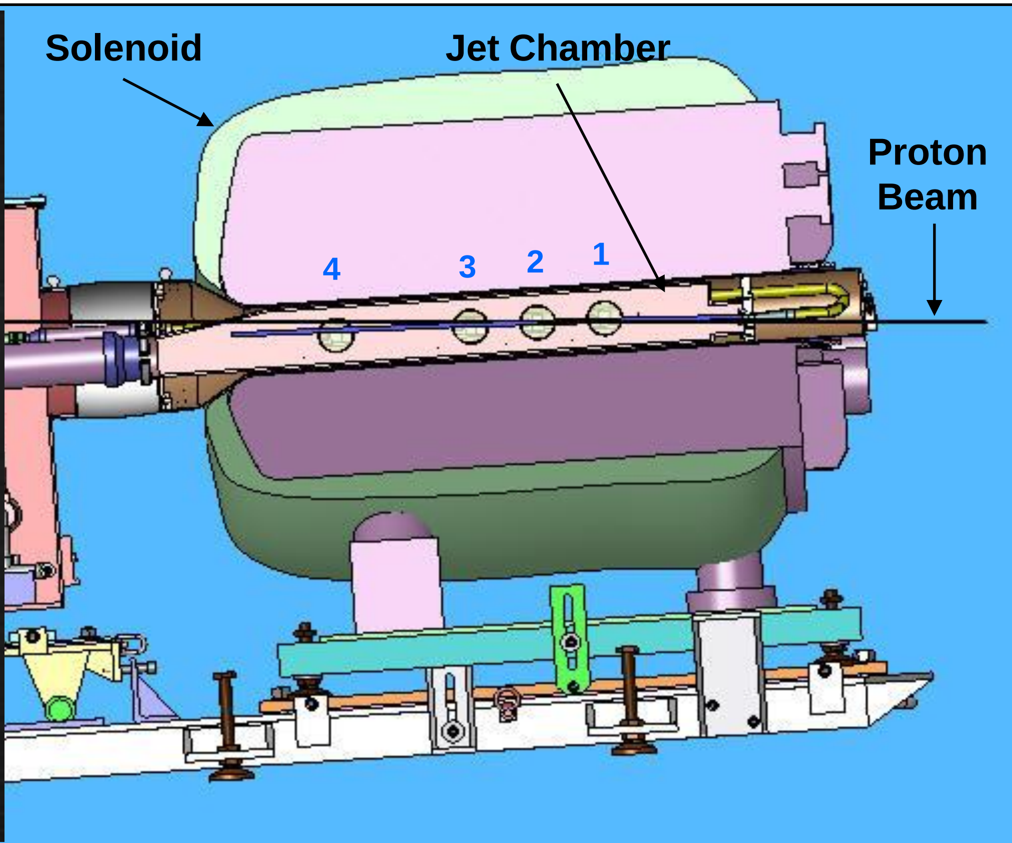
**Based on real designs; depth for ν radiation keeps off site dose <1 mrem/yr*

*** low emittance options are under consideration (discussion below)*

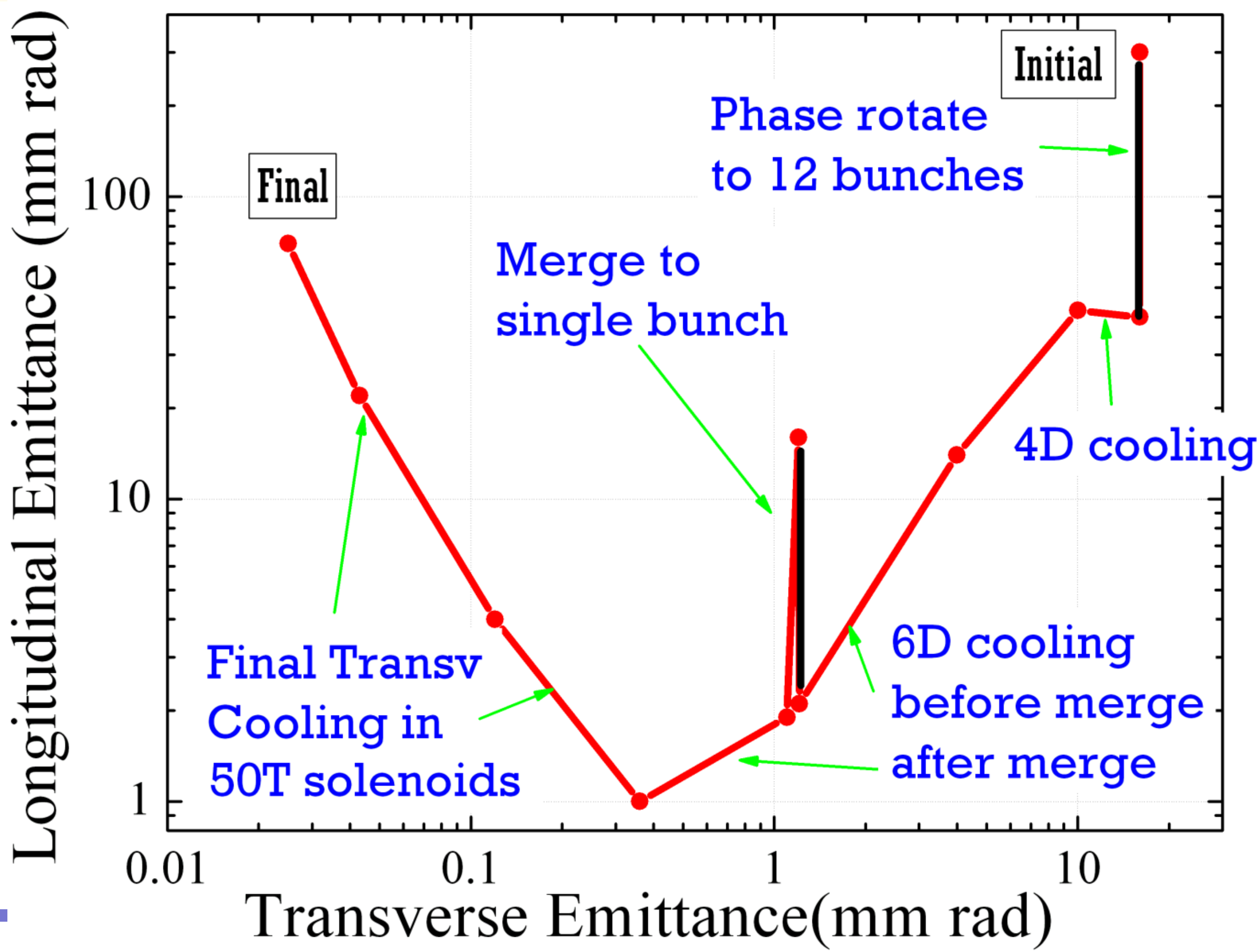
MC/NF Target

- **MERIT experiment**
  - Demonstration at CERN of 1 cm dia 20 m/s Hg jet target in 15 T & 3e13 24 GeV protons
  - target concept has been validated for 4MW 50Hz

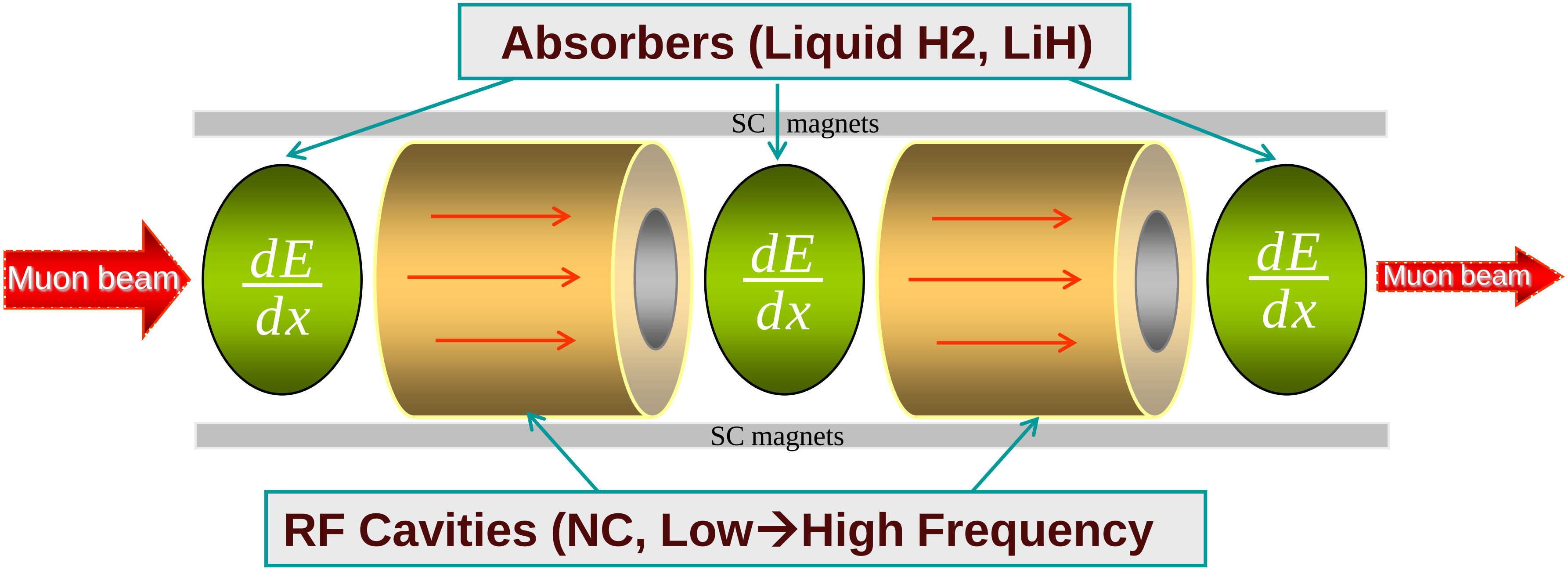




Emittances vs Stage

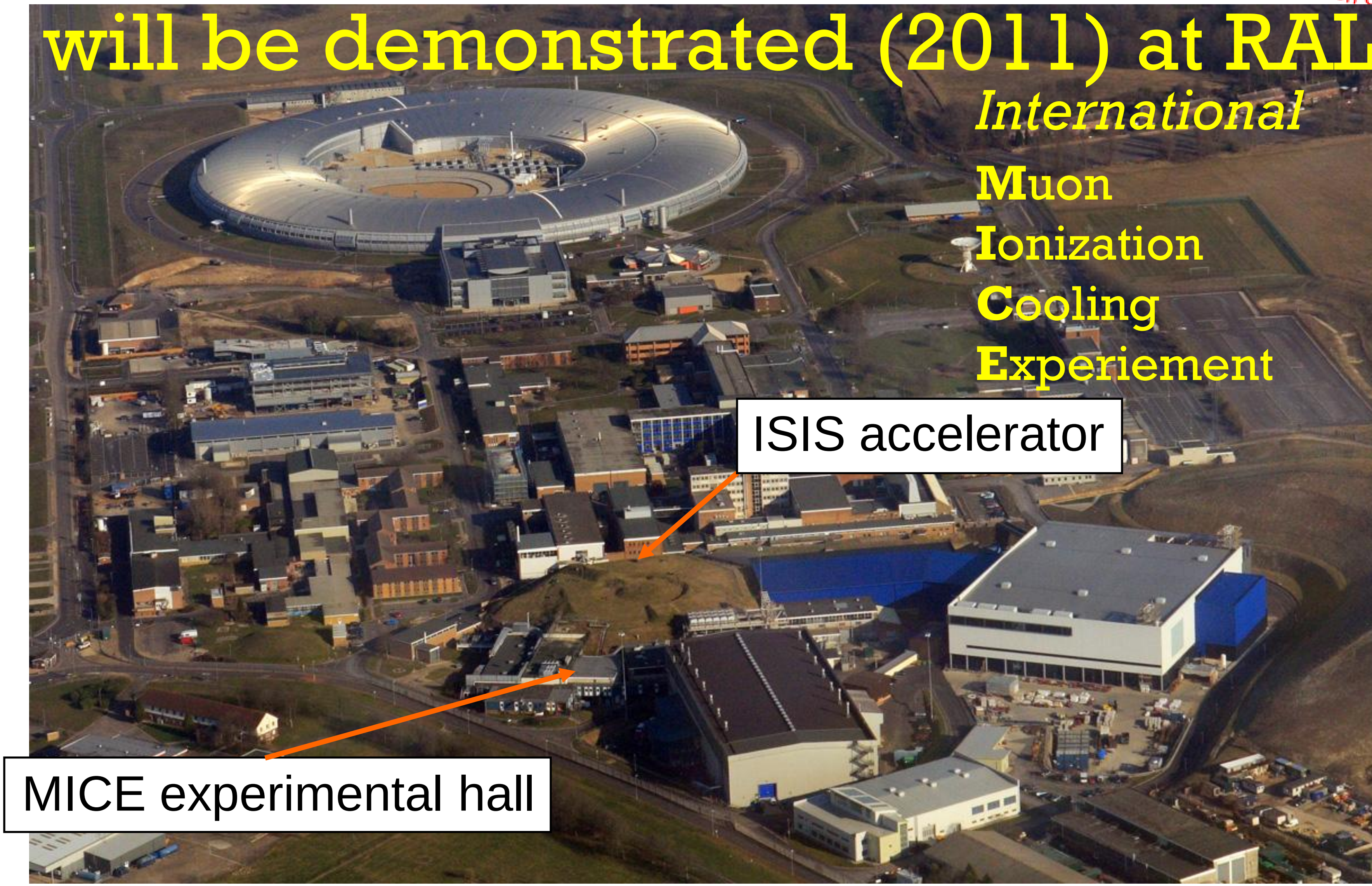


Ionization Cooling is the Key



- There is no “mystery” in the ionization cooling
  - single particle physics well understood to simulate
  - seen in low-*E* *p*-rings (Novosibirsk 60’s, Osaka ERIT ‘08)
  - experiment(s) are to address technical challenges

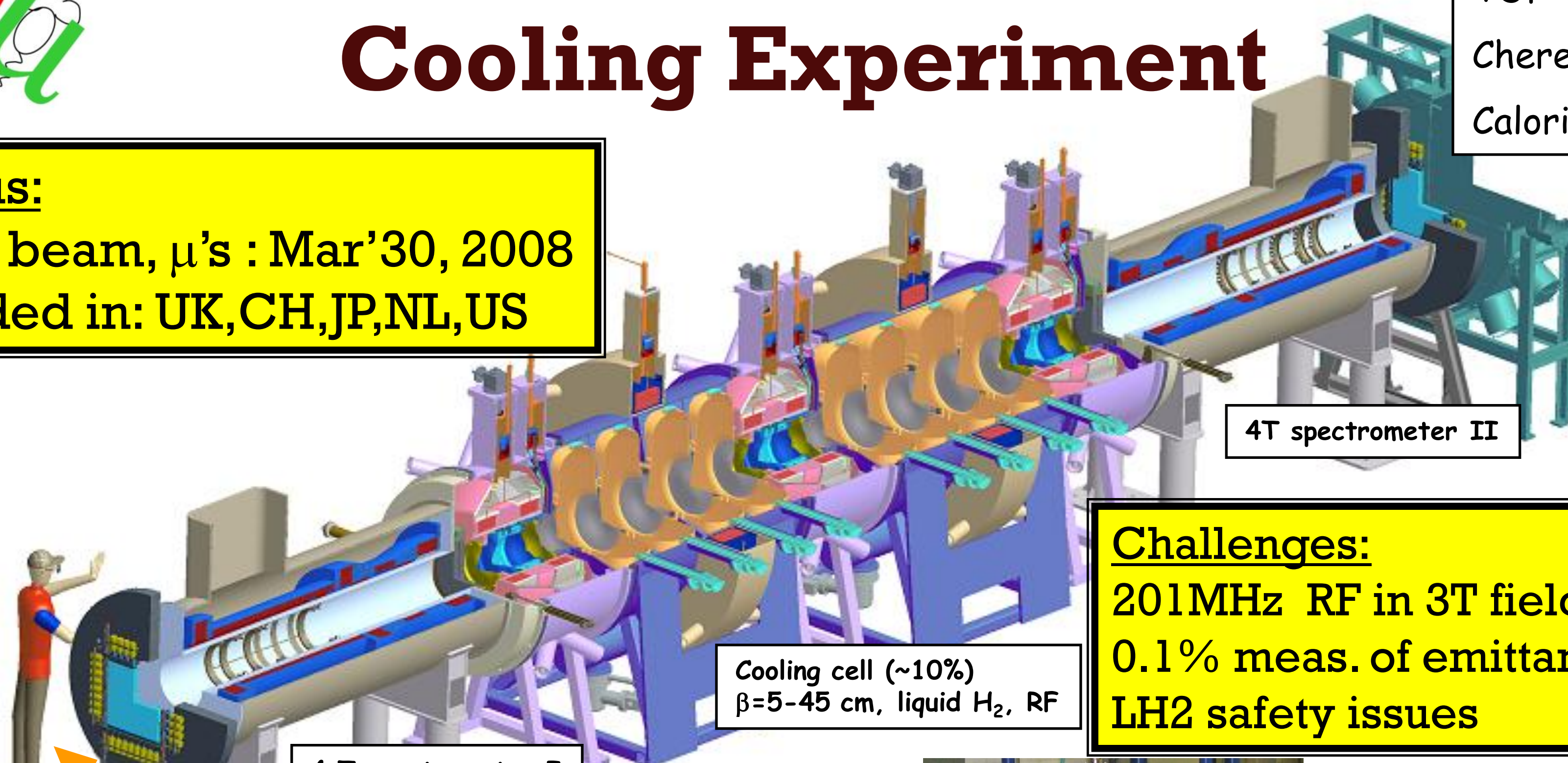
4D-Cooling


will be demonstrated (2011) at RAL
International
Muon
Ionization
Cooling
Experiement
ISIS accelerator
MICE experimental hall

Muon Ionization Cooling Experiment

Final PID:
TOF
Cherenkov
Calorimeter

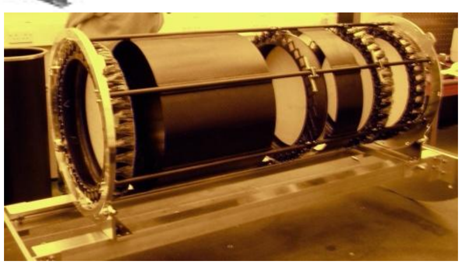
Status:
First beam, μ's : Mar'30, 2008
Funded in: UK,CH,JP,NL,US



Challenges:
201MHz RF in 3T field
0.1% meas. of emittance
LH2 safety issues

Single-μ beam
~200 MeV/c

Some prototyping:



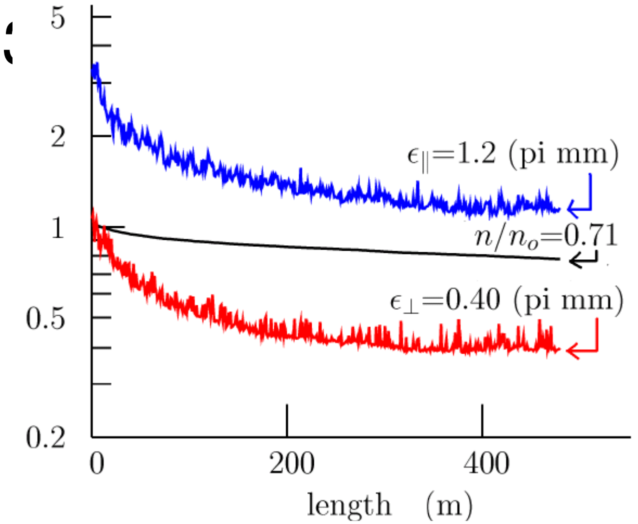
Scintillating-fiber tracker

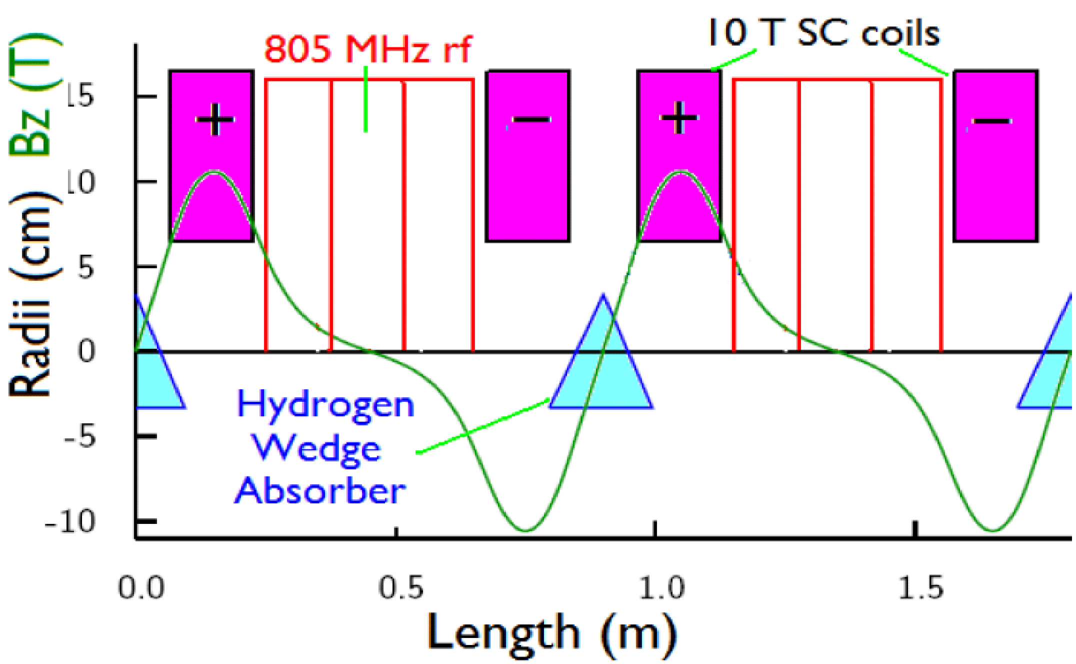
MUCOOL Liquid-hydrogen absorber

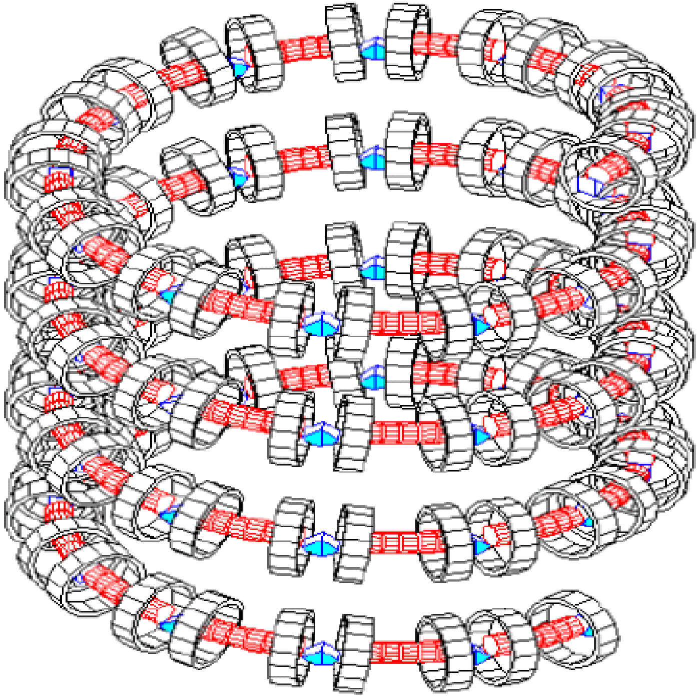
MUCOOL 201 MHz RF cavity with beryllium windows

6D- Cooling: Baseline

- *Guggenheim* lattice - as for slide 1:
  - lattice arranged as helix
  - bending gives dispersion
  - higher-*p* = longer path in wedge absorbers → giving long. cooling
  - *Q: RF breakdown in 3-10 T field*



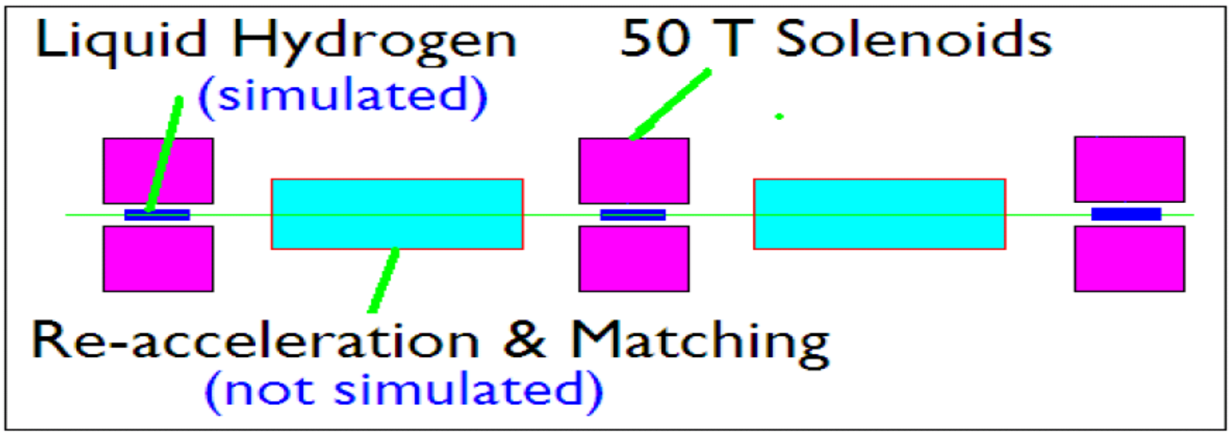




"Final-" Transverse Cooling

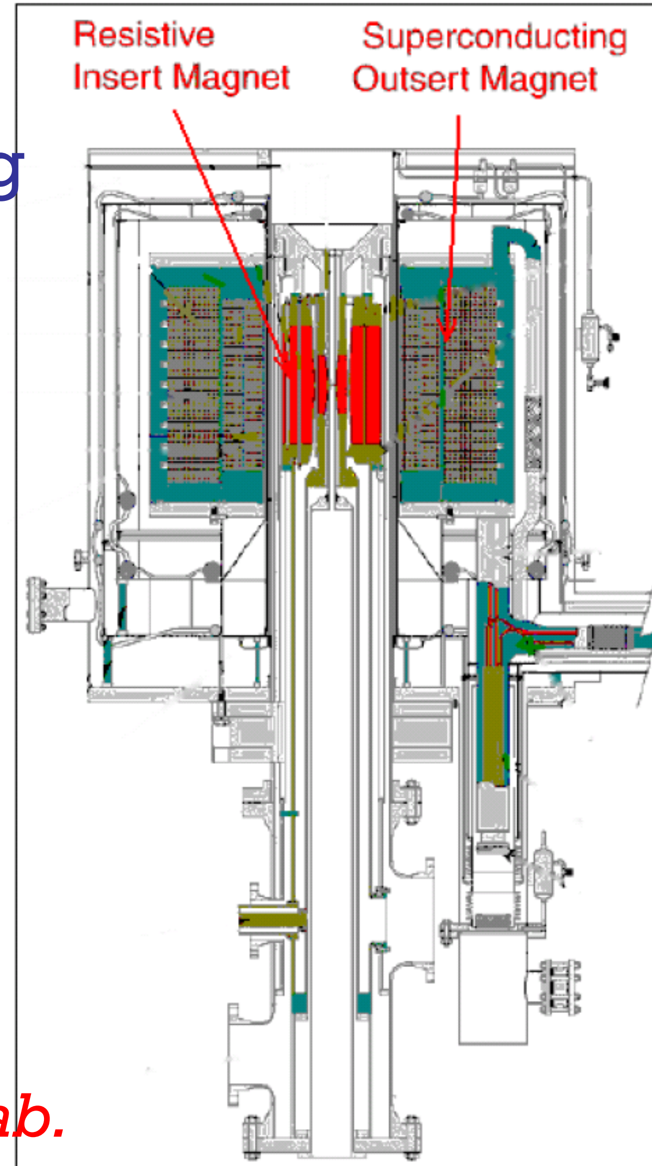
❖ *High Field Solenoids:*

- low momenta and strong focusing allow low transverse emmittance
- longitudinal emittance rises



❖ *40/50 T solenoids :*

- ✓ 45T hybrid at NHMFL, but 30MW
- ✓ 30T all HTS under construction
- ✓ *Conductor → Magnet R&D: HTS Collab.*



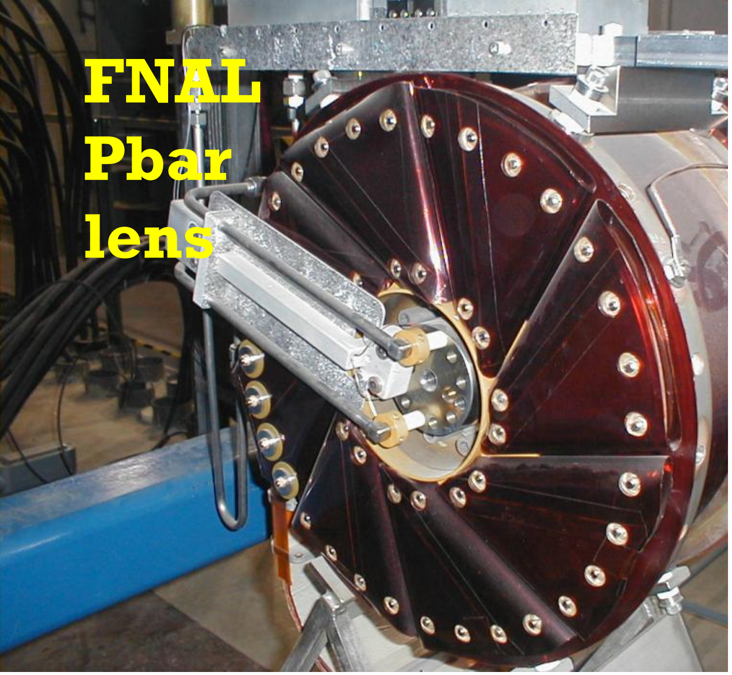
NHMFL 45 T Hybrid Magnet

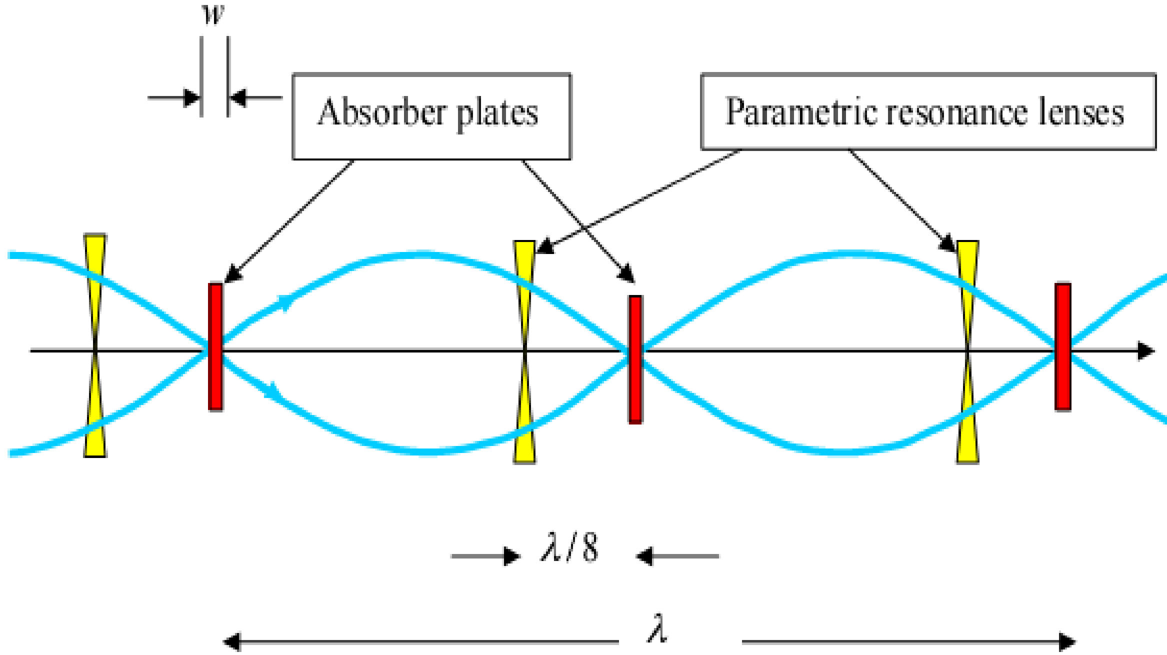
Alternatives Under Study

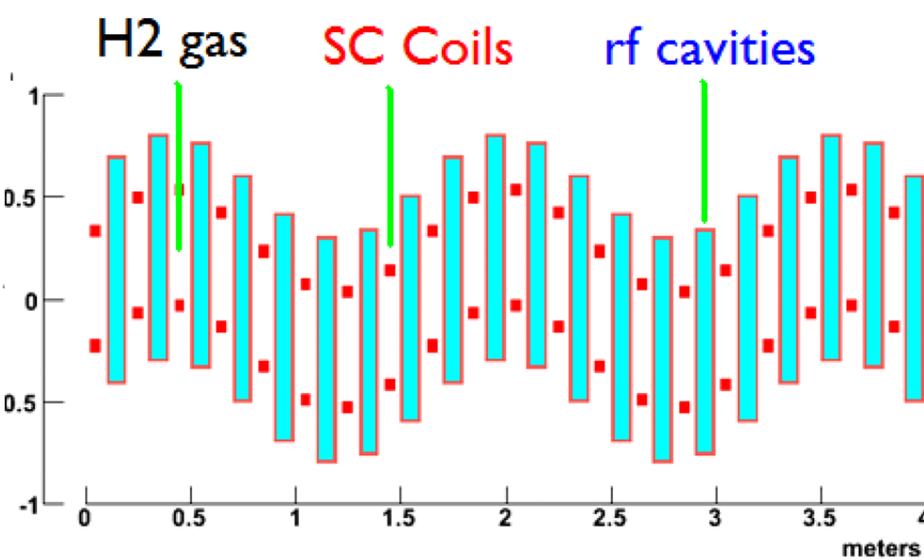
- 6D Cooling:
  - Helical Cooling Channel (HCC)
  - Tilted Coils channel (FOFO Snake)

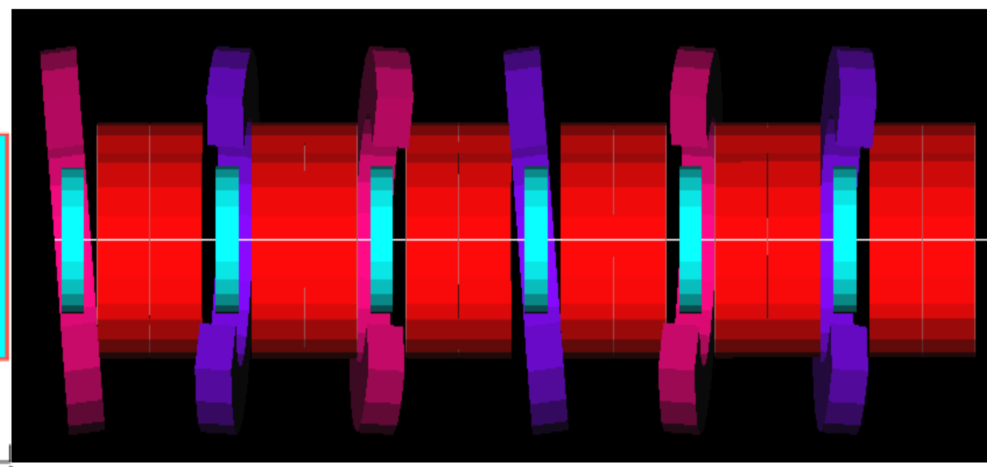
  both allow to cool both signs μ+ μ-

- Final Transverse Cooling:
  - Resonant Lattice (low-β PIC)
  - Liquid Li Lenses (0.5Hz → 5-10Hz)


FNAL
Pbar
lens

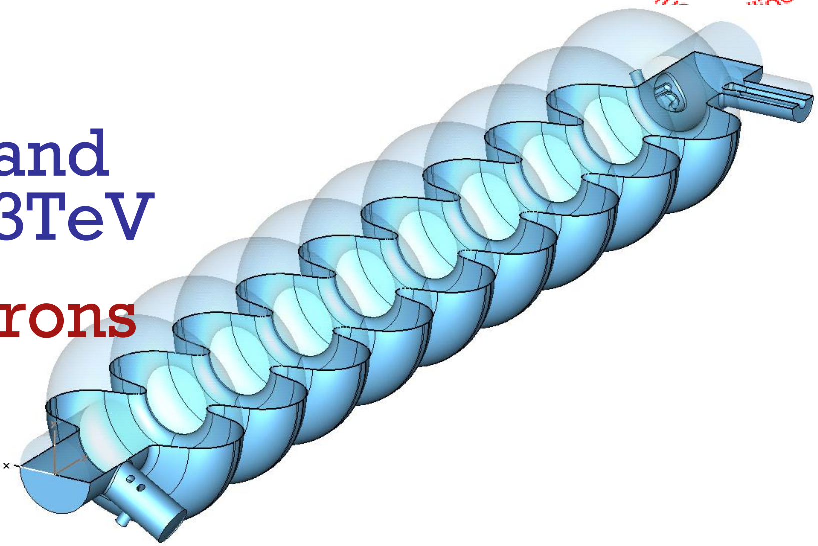

w
Absorber plates
Parametric resonance lenses
λ/8
λ


H2 gas
SC Coils
rf cavities
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
meters

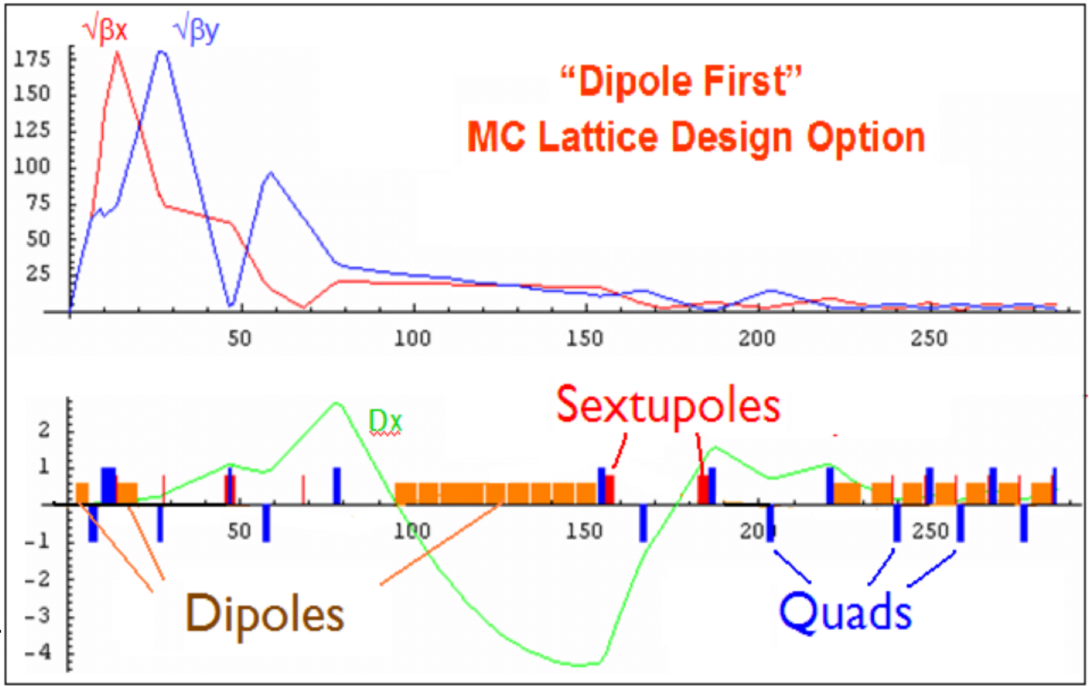


Acceleration and Collider

- **Acceleration**
  - rapid acceleration in linacs and RLAs, <90MW wall plug for 3TeV
  - lower cost – pulsed synchrotrons *prototyping needed*
  - FFAGs can also play a role



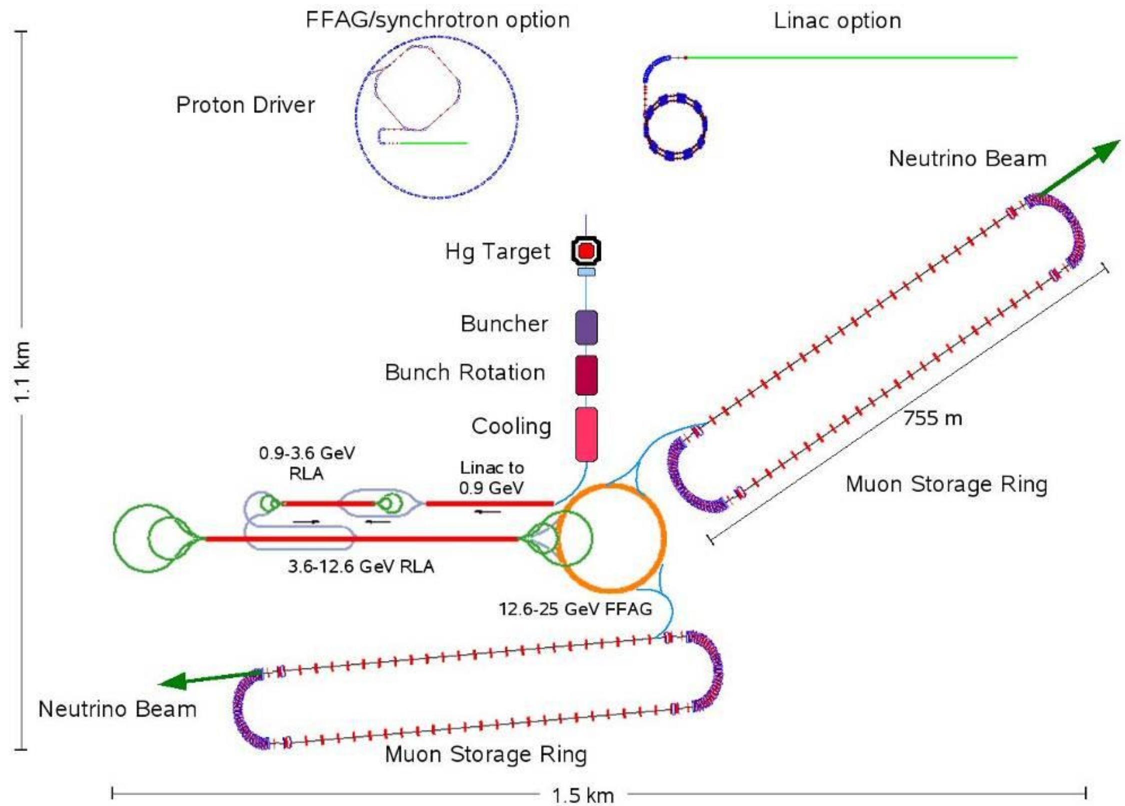
- **Collider Ring**
  - 1.5 TeV designed
  - *to be studied: Detector backround with early dipole scheme*



Neutrino Factory

❖ NF International Scoping Study (ISS-NF, 2005-2008) is finished, reports published (arXive → JINST):

- Physics
- Accelerator
- Detector



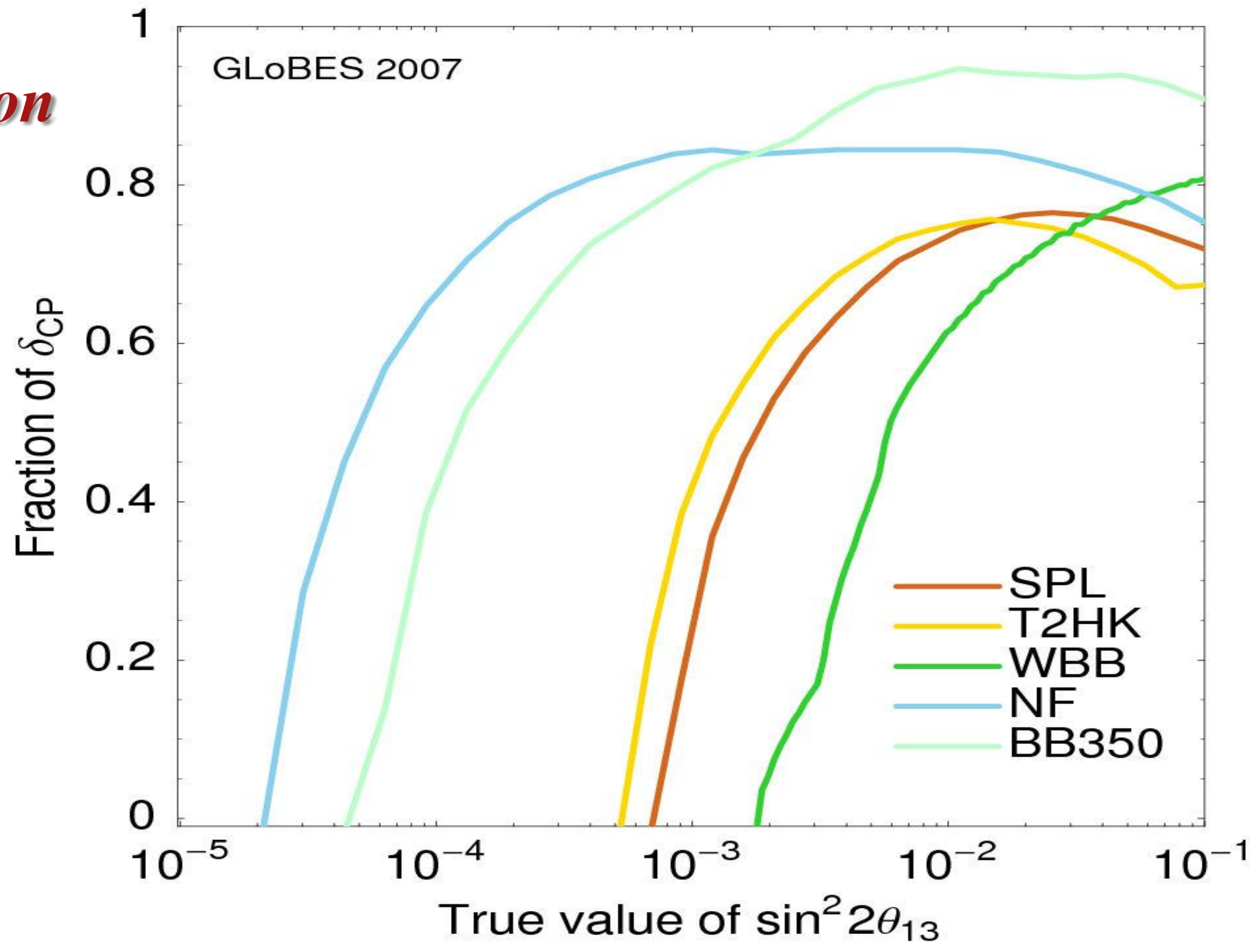
Neutrino Factory Parameters

NF ISS Report

# of μ decays/yr/baseline	**5×10^{20}**
Number of rings(baselines)	2 (3000 & 7000 km)
Stored μ energy	25 GeV
Mean proton beam power	**4 MW**
Pulse repetition rate	50 Hz
Proton kinetic energy	5-10-15 GeV
Bunch duration at target	1-3 ns rms
Number of bunches per pulse	1-3
Sequential extraction delay	≥ 17 μs
Pulse duration	≤ 40 μs

ISS : NF≡ PRECISION

CP violation



Similarly, NF gives the best Physics Reach for studies of mass hierarchy and in the $\sin^2(2\Theta_{13})$ measurements:

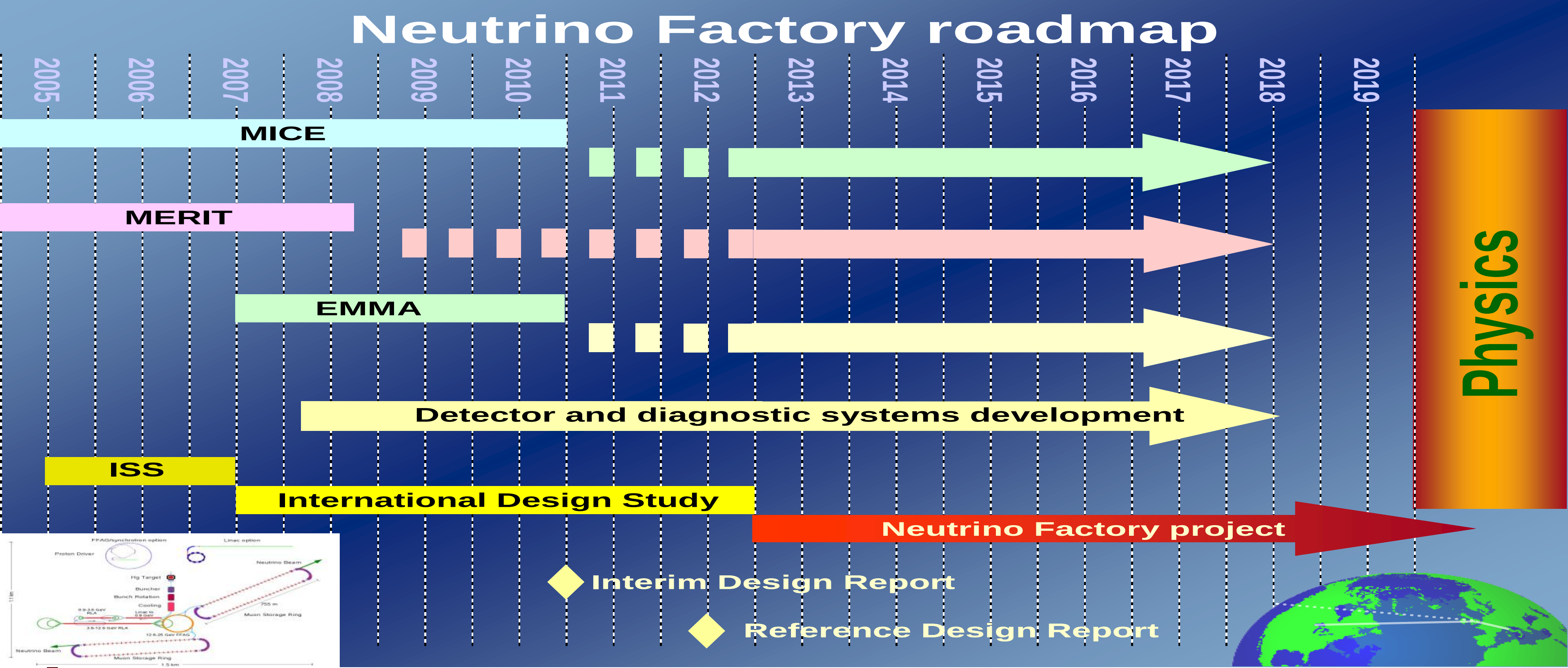
SPL: 4MW, 1MT H_2OC, 130 km BL
T2HK: 4 MW, 1MT H_2OC, 295 km BL
WBB: 2MW, 1MT H_2OC, 1300 km BL

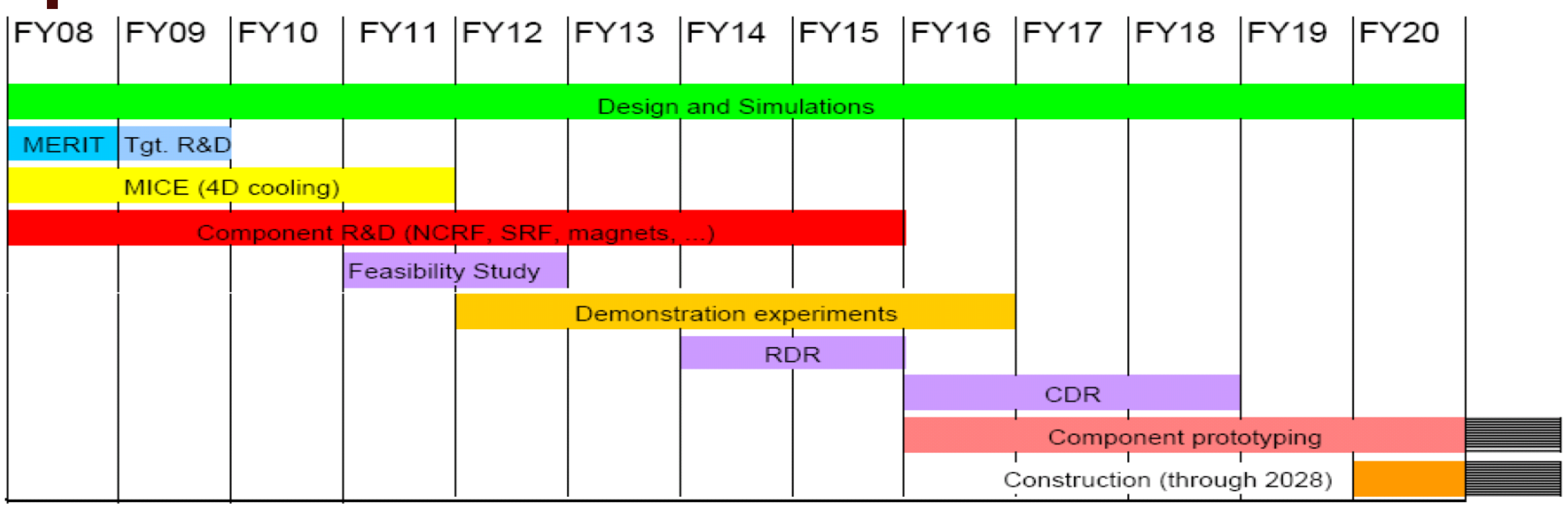
…ev: $\mu+\mu-$ Collider an…

NF: 4MW, 100KT MIND, 4000 & 7500 BL
BB350: γ=350, 1MT H_2OC, 730 km BL

Global Strategy

- 2012-13 Decision Point
  - LHC results establish E_{cm} and L of next lepton collider
  - Muon Collider development plan
    - a study to demonstrate feasibility by 2013 (DFSR)
    - μ-beam demonstration experiments (next 7-10 yr)
    - start of MC construction in early to mid-2020's
  - Neutrino Factory plan:
    - complete MICE experiment by ~2011
    - carry out International Design Study (IDS-NF) to deliver NF-RDR in 2012
    - preconstruction R&D → construction start in late 2010's


Neutrino Factory roadmap
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
MICE
MERIT
EMMA
Detector and diagnostic systems development
ISS
International Design Study
Neutrino Factory project
Interim Design Report
Reference Design Report
Physics


FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20
Design and Simulations
MERIT
Tgt. R&D
MICE (4D cooling)
Component R&D (NCRF, SRF, magnets, ...)
Feasibility Study
Demonstration experiments
RDR
CDR
Component prototyping
Construction (through 2028)

Activities and Resources

- US activities with overlapping memberships
  - Neutrino Factory & Muon Collider Collab. (NFMCC)
  - Fermilab's Muon Collider Task Force (MCTF)
  - Experiments MICE, MERIT, EMMA (all - int'l)
  - SBIR funded companies Muons Inc, Tech-X, PBL
- Guideded by "Coordinating Group"
- Reviewed by Technical Advisory Committee
- Most of the US funding from DoE OHEP:
  - ~(7-8) M$/yr (~30 FTEs) - at present
- About the same level in Europe:
  - mostly from UK NF and EUROnu

US Muon Accelerator R&D Program
5 yr plan (2009-2013)

- Program Management
  - 1. Design
    - 1.1 Physics & Detector
    - 1.2 Design& Simulations
    - 1.3 Cost Estimate
    - 1.4 NF IDS/RDR
  - 2. Components and tests
    - 2.1 MICE
    - 2.2 Cooling Ch. RF
    - 2.3 Magnets
    - 2.4 6D Cooling comp &test
    - 2.5 Other R&D

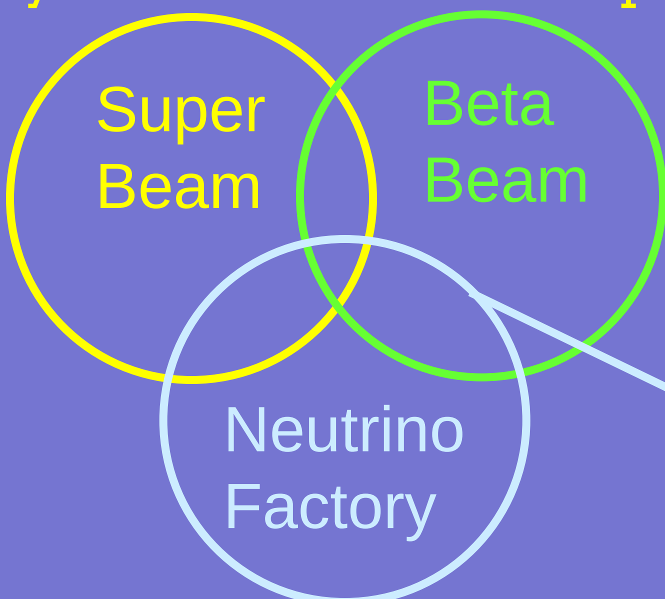
The 5 Year Plan

- **Will address key R&D issues, including**
  - Study RF gradients in magnetic field (magnetic insulation)
  - High pressure RF tests with ionizing beam
  - 6D cooling section prototype
  - Full start-to-end simulations
  - Bunching ring design
  - magnet designs for acceleration, collider and HTS
- **Deliverables:**
  - MC Design Feasibility Study Report and NF RDR
  - Results of hardware R&D to make technology choice
  - Cost estimate
- **Funding increase needed to ~20M$/yr (about 3x present level)**

IDS-NF : EUROnu and US Plan

- EUROnu *is* the European contribution to the IDS-NF
  - Has started (EU contract began Sep 1, 2008)
  - 1st plenary Mar 23, 2009 at CERN (all welcome!)

EUROnu:
costed performance
by 2012 - CERN decision point



IDS-NF: RDR by 2012
demonstrate feasibility

- **The Americas**
  - **Canada**
  - **USA**
- **Asia**
  - **Japan**
  - **India**
  - **(in the future: China …)**
- **Europe**
  - **EUROnu**

Part of the US 5 yr plan

R&D Facilities

- For the next ~5 years – two main facilities to carry out Muon Accelerator R&D will be:
  - MICE at RAL
  - Mucool Test Area at Fermilab

MuCool Test Area

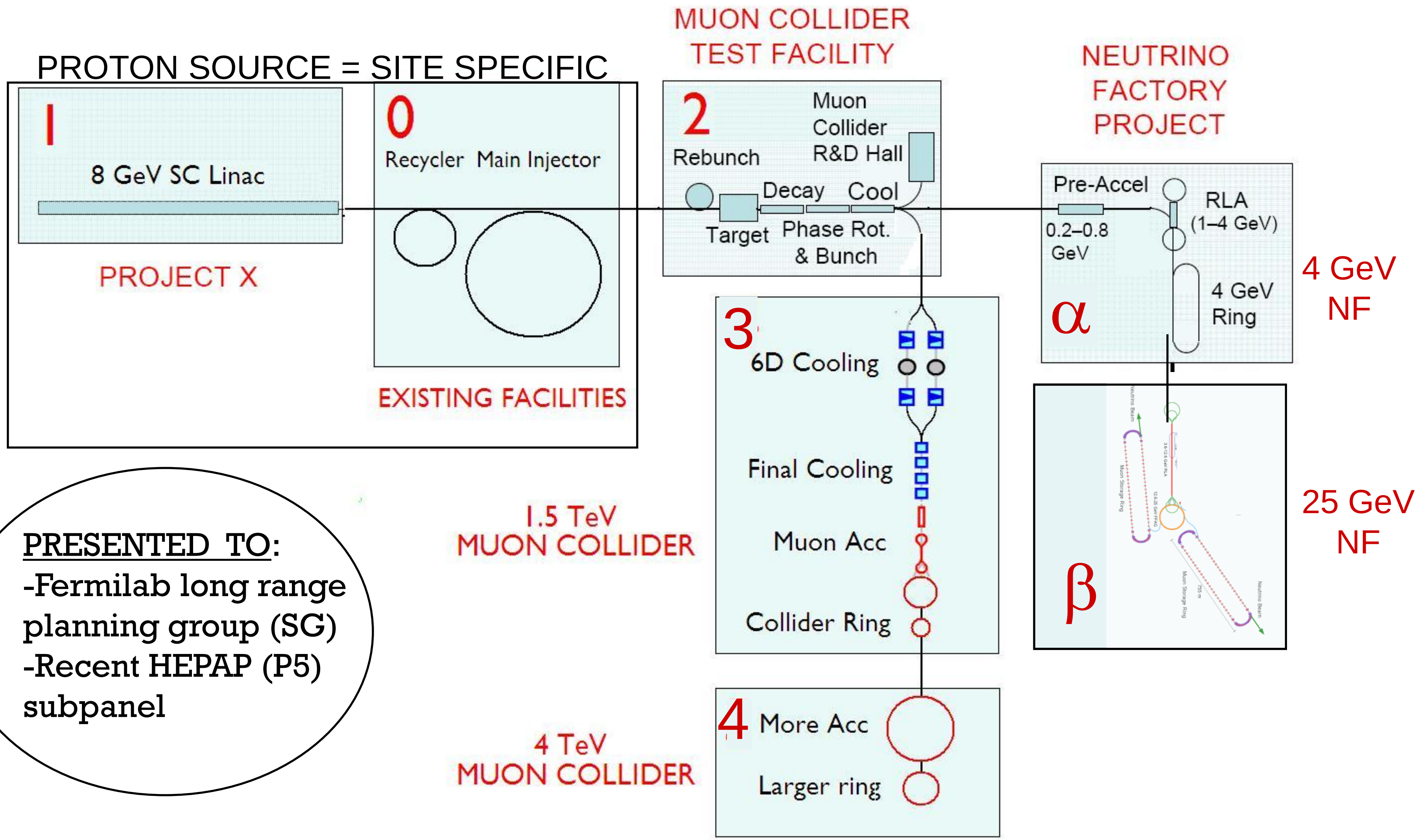
→ cryog
→RF po
→ Liqui
→ 5 T S
(805
→ 400M

R&D Facilities: after 2012

❖ 6D cooling and other full scale tests will require a high intensity beam of muons = a new R&D facility:

- could be synergetic to a muon experiment, e.g., μ2e
- or be part of a new high-intensity Proton Driver facility

Muon Complex Evolution



<u>PRESENTED TO</u>:
-Fermilab long range planning group (SG)
-Recent HEPAP (P5) subpanel

Summary

- A broad and significant R&D programs are already underway in the US, Europe and Japan
- Focus of the programs over the next 5 years:
  - establish feasibility of a Muon Collider by 2012-13
  - deliver MC DFSR by 2013 and NF-RDR by 2012
  - greatly narrow technology options, end-end simul's
  - give cost estimates for MC and NF
- Staged approach: PD → MCTF → NF → MC
- To be realistic option in 2012-13, **increased support** for μ-Collider R&D is needed now

Stars Aligned for Muon Collider

great progress – experiments and conceptual

understanding of outstanding HEP potential

promise of affordable cost and small footprint

strong international team

realistic R&D program toward design reports for μ-collider and ν-factory

?

What's Missing?